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Contents

Fresnel zone plates for Achromatic Imaging Survey of X-ray sources

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Abstract.

A telescope with Fresnel Zone Plates has been contemplated to be an excellent imaging mask in X-rays and gamma-rays for quite some time. With a proper choice of zone plate material, spacing and an appropriate readout system it is possible to achieve any theoretical angular resolution. We provide the results of numerical simulations of how a large number of X-ray sources could be imaged at a high resolution. We believe that such an imager would be an excellent tool for a future survey mission for X-ray and gamma-ray sources which we propose.

Keywords: X-rays and gamma-ray sources, Black holes, X-ray imaging, Fourier optics, Technological research and development

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INTRODUCTION

The usage of Fresnel Zone plate combinations have been suggested to be an excellent way to obtain a very high resolution imaging in X-rays and gamma-rays [1, 2] and several workers, specifically Desai and collaborators [3, 4, 5] have investigated this possibility for over a decade.

The advantage of the zone plate telescope is that, in principle, an arbitrarily high resolution can be achieved by it. The angular resolution is $\delta\theta = \delta y/D$ where δy is the finest zone at the outer boundary and D is the distance between two plates. The plates can be made of materials which is opaque to the observational band-width and it will remain achromatic in the entire range of interest. For instance, a single plate of 1 mm will block about ~ 150 keV photons and with a pair which will cast a shadow on the detector system one would achieve the identical angular resolution even at 250 keV without any problem. The major problem appears to be the pointing accuracy of a detector system. In fact, with a pair of zone plates of ~ 30 mm diameter with $50\mu\text{m}$ outer zone at a distance of 10m, one can have a resolution of about an arc second. This is achievable. With the advent of nano technology, one can even conceive of a few nm of the zone width and achievements of a mili-arcsecond of resolution, extending the possibility of directly imaging the immediate vicinity of a super-massive black hole. By increasing the distance between the plates (as in two satellites) even higher resolution (e.g., micro arc seconds) could be achieved. Fairly close binary X-ray sources (such as WW Aurigae)

could also be resolved easily.

While achieving achromatic images over a large energy range, the thickness of a plate has to be large. As we mentioned, for a tungsten plate, to have an image at 150 keV , we need to have the plate-thickness of $d = 1 \text{ mm}$. Similarly, to achieve high resolution, we require δy to be low. This limits the highest possible angle ($\delta y/d$ rad for $\delta y = 50 \mu\text{m}$ and $d = 0.1 \text{ cm}$) of the source whose photons can enter through the transparent zone. Thus, the survey will have to be made from a narrow field collimator. In order to achieve statistically significant photon count, survey has to be done with a mosaic mode and not by continuously scanning the sky.

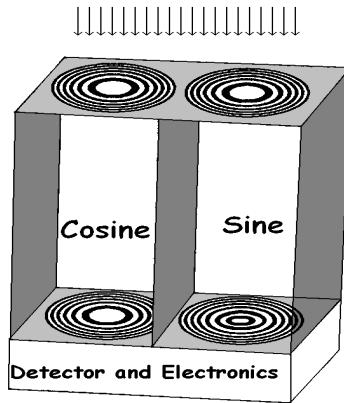


FIGURE 1. Schematic diagram of the experimental set based on which the simulation is made. One set of Cosine and one set of Sine combinations are kept side by side. In the detector box, we assume a CMOS CCD detector of $50 \mu\text{m}$ pixel width.

In the present paper, we propose a survey mission of the sky at wide band of X-rays energies (i.e., $\sim 1 - 250 \text{ keV}$ range) with a moderately high resolution. In Fig. 1, we show a typical zoneplate telescope with two pairs of zone plates, one pair is of *Sine* type and the other pair is of *Cosine* type. Both are positive (i.e., the central zones are transparent to X-rays). We present simulation results which show distribution of photons on the detector plane. We then carry out Inverse Fourier Transformation to retrieve the source distribution. Cosine combination of zone plates consists of zones whose radii vary as \sqrt{n} and Sine combination consists of zones whose radii vary as $\sqrt{n - 1/2}$.

SIMULATIONS RESULTS

For the sake of concreteness, we concentrate on the simulation of cases with only two sources and twelve sources in the field ($2^\circ \times 2^\circ$). We assume zone plates of 34mm diameter and $50 \mu\text{m}$ as the smallest zone thickness. The tungsten made plates are of 1mm thick and they are separated by 30cm . A CMOS CCD (1024×1024 pixels with $1 \text{ square pixel} = 50 \mu\text{m}^2$) is assumed to act as the detector. θ in degrees (measured from the vertical axis clockwise) and ϕ in arc seconds (measured from the axis of symmetry of the zone plate) define the nature of off-axisness of the source.

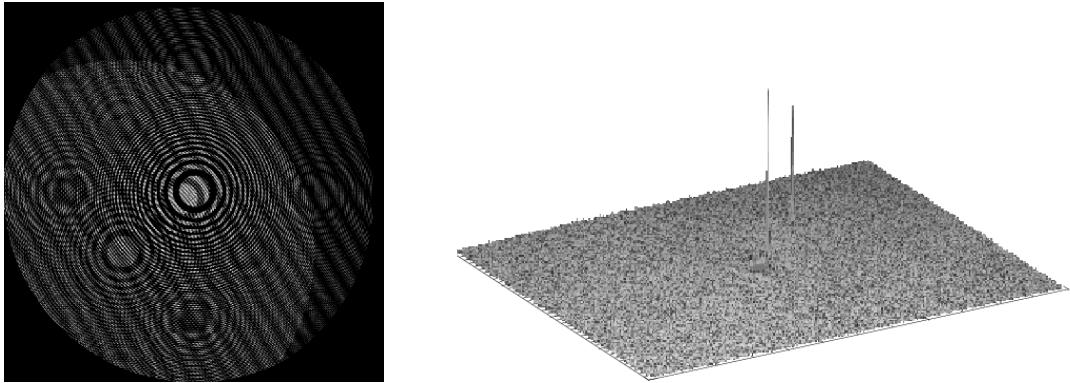


FIGURE 2. (a) Simulated Moire Fringe patterns on the detector plane when two sources are placed at 800 arcsec and 5000 arcsec off axis locations. (b) Three dimensional reconstruction of the photon counts with the base FOV $2^\circ \times 2^\circ$.

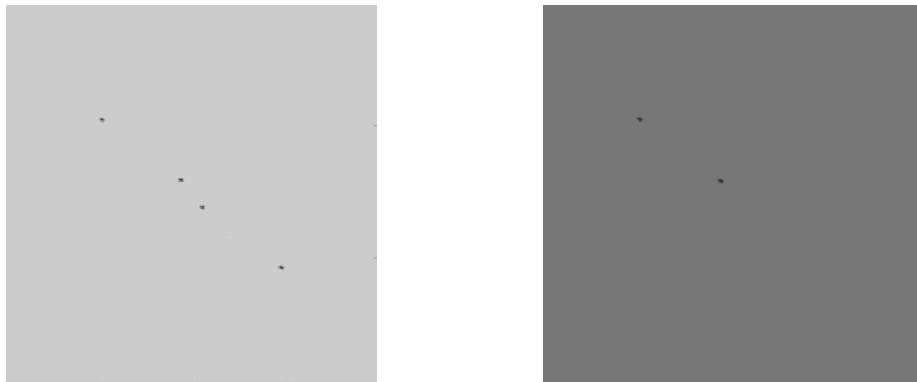


FIGURE 3. (a) Reconstruction of the two sources from Fig. 2a using only the Cosine transformation. Note that there are two sets of sources symmetrically placed. (b) Same as in (a) except using both the Cosine and Sine transformations.

CONCLUDING REMARKS

Zone plate combinations are remarkably achromatic high resolution X-ray imaging devices which are suitable for space applications. We show that very high resolution may be obtained with suitable choice of distance and zone parameters.

ACKNOWLEDGMENTS

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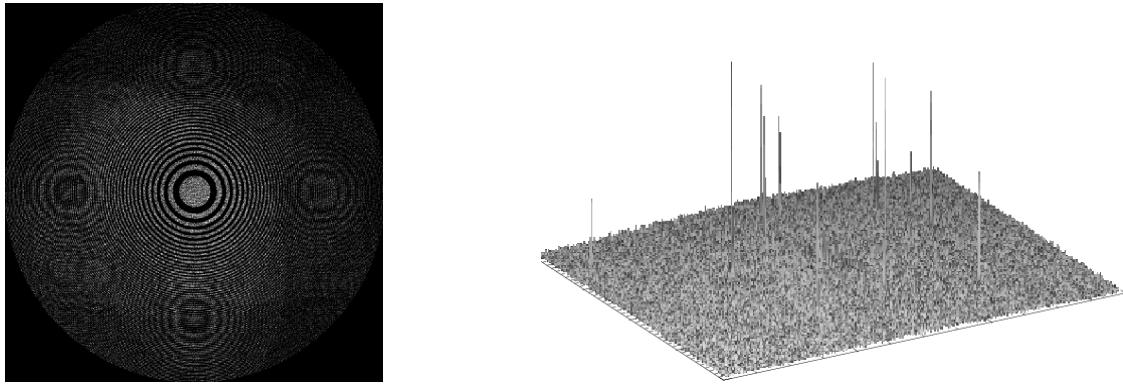


FIGURE 4. (a) Simulated Moire Fringe patterns on the detector plane when twelve sources are randomly placed. (b) Reconstruction of the three dimensional image of the photon counts for the twelve sources in a $2^\circ \times 2^\circ$ field.

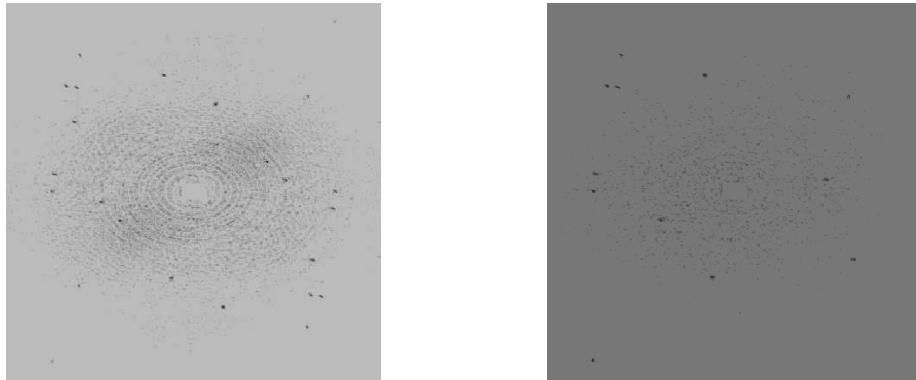


FIGURE 5. (a) Reconstruction of the twelve source locations from the Fig. 4a using only the Cosine transformation. Note that there are two sets of twelve sources are symmetrically placed. (b) Same as (a) except using both the Cosine and Sine transformations.

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